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ORIGINAL PAPER

Construction Technology of Micro Bench Cut Method for Weak Rock Tunnel with High In-situ Stress

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Abstract Taking Shanyang tunnel of Dali to Ruili (DaRui) railway as background, the construction technology of micro bench cut method for weak rock tunnel with high in-situ stress is established by combining the full-fgenius tunnelling method and bench cut method. For weak rock tunnel with large deformation, corresponding construction control points and technical characteristics are discussed. The following results are achieved. (1) The horizontal convergence deformation of Shanyang tunnel is larger than that of the subsidence displacement of the vault. Feet-lock bolt, reinforced grouting of arch foot surrounding rock, and expand support measures for arch foot are equipped to increase the stability and resistance of the supporting steel frame. (2) The narrow working surface of a single-line tunnel can be effectively utilized and the rapid construction of tunnel is also realized. (3) The construction technology can realize the rapid closure of the initial support into a ring, ensure the tunnel safety of the IV and V grade surrounding rock, reduce the construction cost, and improve the construction efficiency. The construction methods and techniques proposed in the article can provide reference for similar projects.

Keywords Construction technology · Micro bench cut method · High in-situ stress · Weak surrounding rock · Tunnel engineering

1 Introduction

With the implementation of China's "transportation power" strategy, the infrastructure construction in the central and western regions has been further strengthened. The construction of highway, railway and other traffic facilities has entered the peak period. At the same time, the economy of the central and western regions will be improved by the construction of infrastructure. As the central and western regions are mainly mountainous rivers with high altitude and complex terrain, the deeply-buried long tunnel is constructed in highway and railway projects. During the construction of the tunnel, the geological disasters such as large deformation, rockburst, collapse, water inrush and mud outburst occur. Especially, the large deformation of weak surrounding rock in high in-situ

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stress has always been one of the problems that perplex the safe construction of the tunnel.

With the rapid development of science and technology in recent years, the technology of tunnel construction is developed quickly (Dong 2). Currently, the commonly used construction methods for traffic tunnel, such as railway tunnels, highway tunnels and subway tunnels mainly include full-fgenius tunnelling method, bench cut method, annular excavation reserved core soil method, Center Diaphragm (CD) method, and Cross middle door (CRD) method, the double-side pilot pit method, among which the bench cut method is a common method. For example, Huang (3) analyzed the influence of the length, height and flatness of the benches on the stability of the tunnel. Li et al. (7) studied the deformation characteristics of the arch springing and destabilization mode of surrounding rocks by combining with numerical analysis software. Du et al. (4) researched the impact of the bench method construction of the new small-distance tunnel on the safety of the existing tunnel. Liu et al. (6) investigated the air-flow structure and gas diffusion behavior in gas tunnel construction through bench cut method. Wang et al. (1) studied the failure and control mechanism of weak surrounding rock of super large section tunnel under excavation by bench cut method and CRD method. The existing research results indicate the bench cut method is mostly used to solve the general geological tunnel excavation problems, and the application and research of the method in the tunnel with high in-situ stress and weak surrounding rock are rare. Therefore, an improved bench cut method is studied for the tunnel with high in-situ stress and weak surrounding rock, which is based on the Shanyang tunnel engineering of Darui Railway.

2 Project Overview

Dali to Ruili (DaRui) Railway, which is one of the important lines of China to Myanmar international railway, has a great and far-reaching influence on boosting the economic and social development of the areas along the line and promoting the exchanges and cooperation between China and Southeast Asian and South Asian countries. Shanyang tunnel is one of the major and difficult control projects of the Darui Railway. The 13,390 m long tunnel of Shanyang has the maximum buried depth of 1015 m. The geological structure of Shanyang tunnel is complex and changeable. During the project construction, large deformation, water rich, cracking and local collapse of surrounding rock often occurs.

The available information reported in Zhao (2017) shows that Shanyang tunnel has repeatedly traversed through high in-situ stress and weak fractured zones. Its main grade of surrounding rock are IV and V. Excavation of the face reveals that the mudstone is thin-layered and flaky, with developed joints and fissures, obvious compression fold and poor self stability. Figure 1 demonstrates the geologic diagram of shanyang tunnel.

3 Construction Technology of Micro Bench Cut Method

In order to ensure the construction safety of tunnel and realize the closure of the initial support into a ring as soon as possible, the micro bench cut method is adopted by improving the bench cut method. It is worth noting that the Shanyang tunnel is excavated with upper and lower benches, because the tunnel is a single-track railway tunnel with small tunnel clearance and cross-section.

Figure 2 shows the flowchart of micro bench cut method. First, the excavation of the upper and lower benches is adopted at the same time, and then the initial support of the upper and lower benches is implemented. In the next part, the excavation of inverted arch and the initial support are performed. Finally, the secondary lining is carried out in time according to the monitoring measurement results. Figure 3 demonstrates the flowchart of tunnel section by using micro bench cut method.

Before excavation, the advanced support method should be selected according to the surrounding rock condition of tunnel face. When the surrounding rock is in fractured zone like faults, pipe-shed advance support and pre-reinforcement measures of glass fiber reinforce poly-mer bars on the face should be carried out; under normal conditions, the advanced small pipe should be used. For pipe-shed advance support, the drilling rig operating platform can be trimmed with an excavator. Each pre-drilled hole is positioned and marked by survey crew at the same time. C6 drilling rig is used to drill holes, then pipe shed is constructed and grouting is carried out. For fiberglass anchor rod

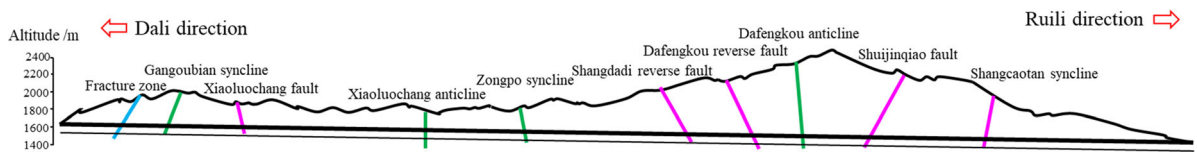


Fig. 1 The geologic diagram of shanyang tunnel

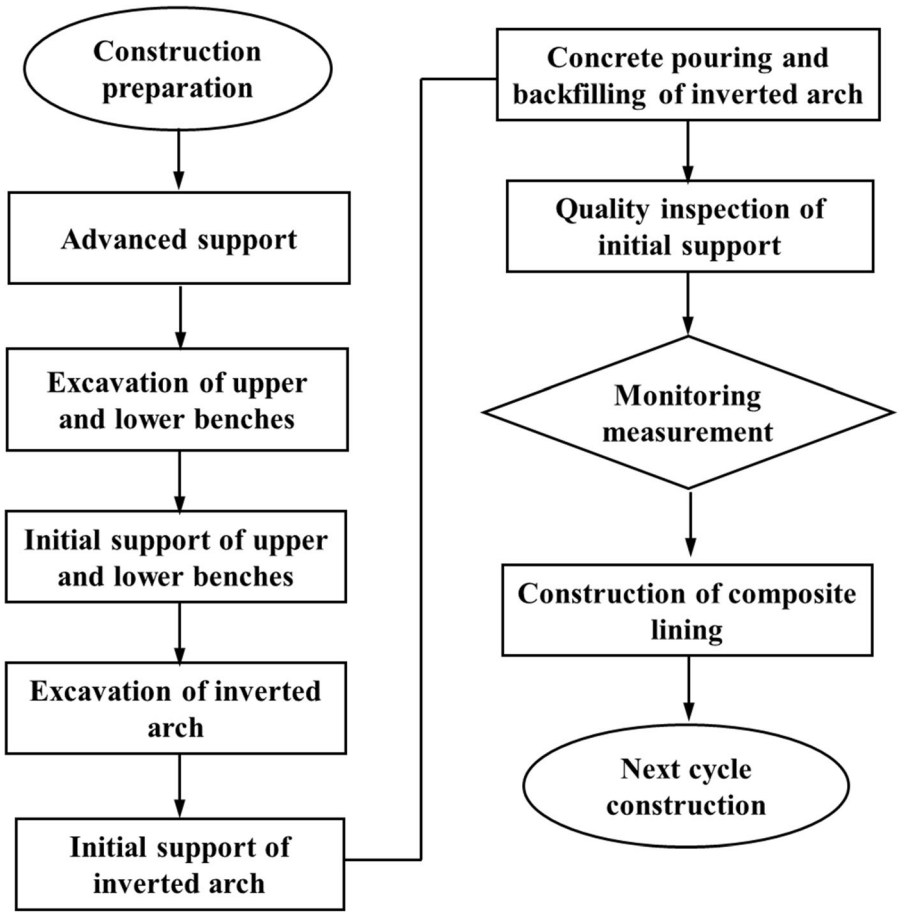


Fig. 2 Flow chart of the micro bench cut method

support, YT28 drilling rig can be used for drilling construction and anchor rods can be placed and grouted according to design requirements. Figure 4 exhibits the advanced support of tunnel.

For the first time, the part of ① and ③ was excavated by manual cooperation with machinery. The mechanical excavation is carried out with the matching device of the twin header and the excavator. The twin header device used in the tunnel is shown in Fig. 5. The part of ① is firstly excavated. A certain size groove is opened in the center of the part of ①, and then it is excavated from top to bottom along the center of the section to the left or right until the excavation of the part of ① is completed. Figure 6 displays the construction sequence of the mechanical excavation of twin header. After the excavation of the part of ① is completed, the muck from the upper bench is directly picked up to the lower bench, and then the excavation of the part of ③ is carried out. The excavation sequence is the same as the part of ①. Then, the Electronic Total Station was used to measure the excavation section. The measurement process and

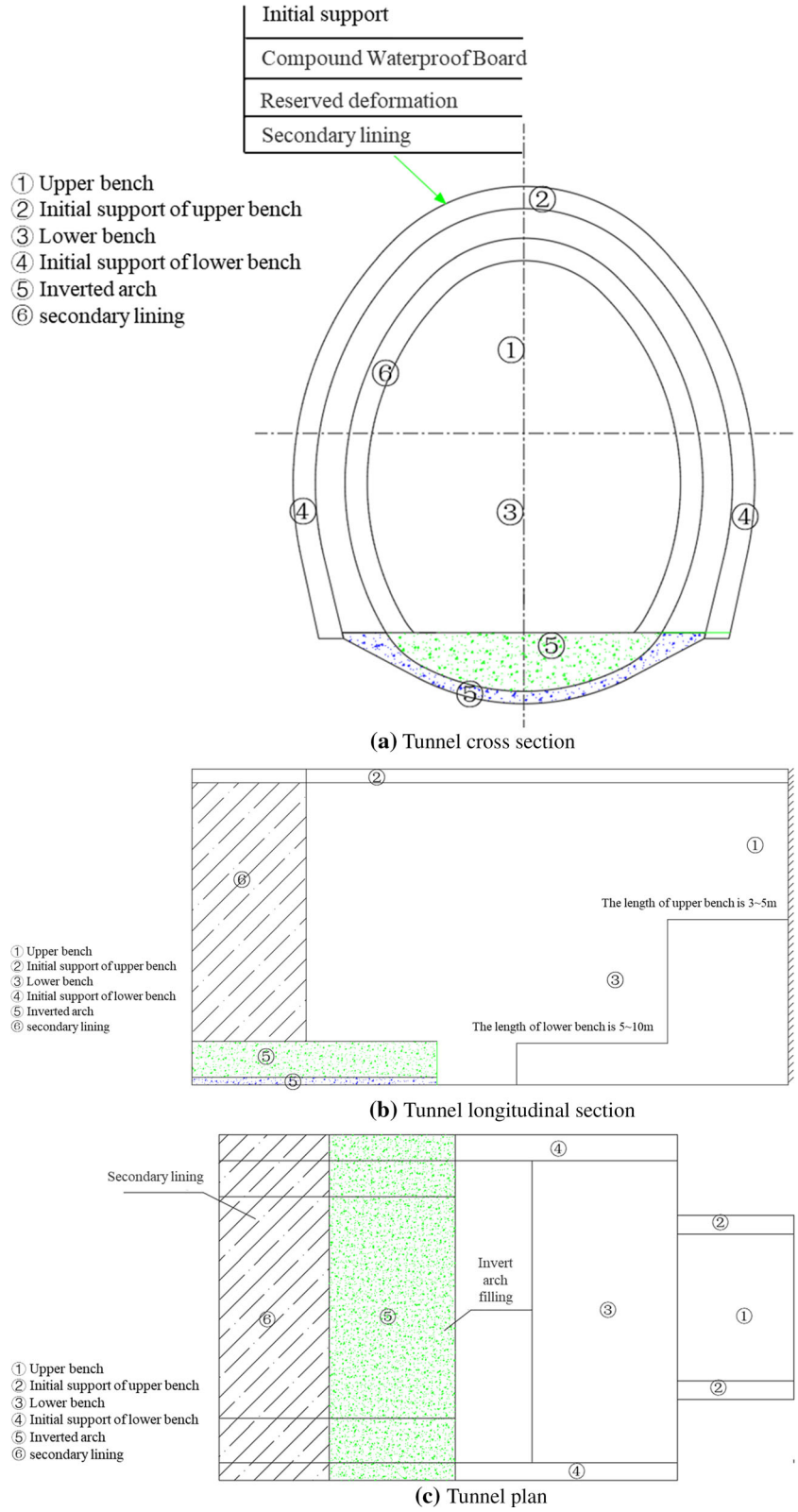
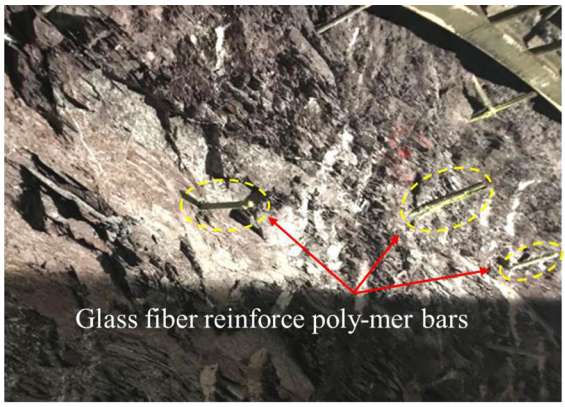
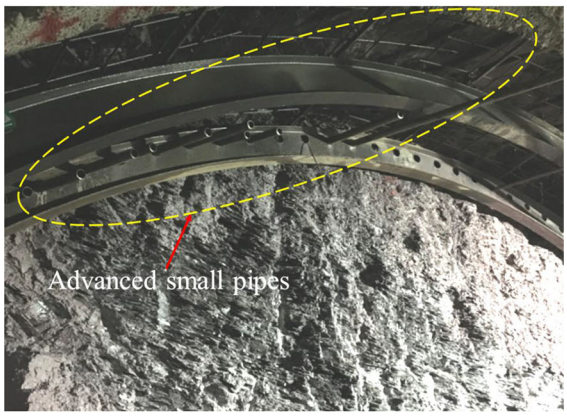


Fig. 3 Schematic diagram of tunnel section by using the micro bench cut method



(a) Application of glass fiber reinforce poly-mer bars



(b) Application of advanced small pipes

Fig. 4 Advance support measures of tunnel

Fig. 5 Twin header device

results are exhibited in Fig. 7. The excavation contour line is basically consistent with the design contour

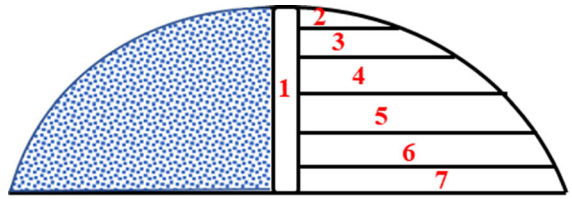


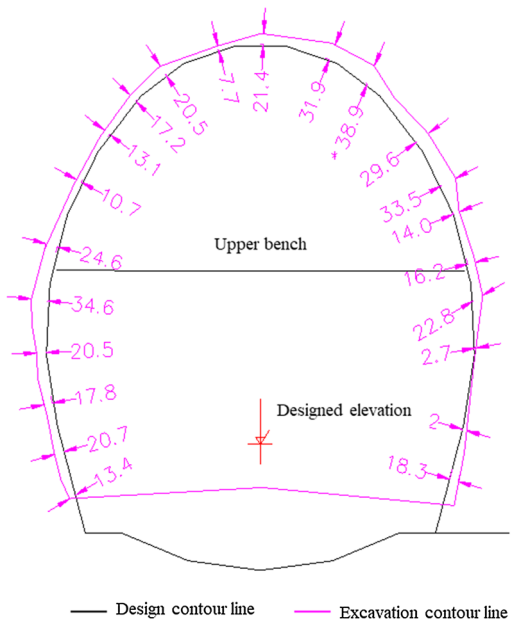
Fig. 6 Construction sequence of twin header device (The excavation sequence is represented by 1–7)

line, except that the excavation facing the right side of the tunnel face has obvious over-excavation. This part of the over-excavation mentioned is mainly due to the fragmentation of the surrounding rock, resulting in falling blocks. Thus, the initial shotcrete after the excavation of the face should be used. The muck of excavation section can be directly picked up to the position where the excavator can load the muck. The PC200 excavator and the Hongyan dump truck are used to load and transport the muck, respectively. When the muck is discharged, the initial support of the upper bench ② should be implemented according to the design parameters. The feet-lock bolt is applied at the arch foot position of the upper bench, and at the same time as the initial support of the lower bench ④.

According to the monitoring and measurement results, the inverted arch (the part of ⑤ in Fig. 3) is excavated mechanically. The inverted arch is usually excavated at a distance of 25–35 m from the lower bench. When the monitoring data show that the surrounding rock is large deformation, the inverted arch is excavated at a distance of 5–10 m from the lower bench. Each excavation of inverted arch can not exceed 3 m, and the initial support of the inverted arch should be implemented according to the design parameters. Then the re-bar binding of inverted arch and the waterproof lining are implemented, and finally the inverted arch and low sidewall are poured with concrete.

The lining trolley is used to pour the initial support ⑥ (secondary lining). Before pouring, the section of the initial support is scanned to ensure that the thickness of the secondary lining meets the design requirements. The exposed steel and sharp object on the initial support surface are removed. The waterproof and drainage of secondary lining is constructed. Finally, the lining trolley is used to pour concrete on the treated surface.

(a) The measurement process of the Electronic Total Station



(b) The excavation contour line and the design contour line

◀**Fig. 7** The measurement process of the Electronic Total Station and results

4 Construction control points

(1) The length and height of bench excavation are strictly controlled. The length of the upper bench is controlled to be 3–5 m, and the height is 4.5–4.8 m. The length of the lower bench is controlled to be 5–10 m, and the height is about 5 m. Inverted arch is formed by one-time excavation, and its excavation height and length are respectively controlled at about 1.76 m and 3–6 m. The safe distance of second lining is usually controlled within 70 m. When the monitoring data show that the surrounding rock is large deformation, The safe distance of second lining is adjusted within 30 m.

(2) The principle of short footage, strong support, early closure and frequent measurement is adhered to in tunnel construction.

(3) In order to increase the stability and resistance of the steel frame, feet-lock bolts are set up 50 cm and 100 cm above the connecting plate of the arch frame and 50 cm below the connecting plate. Longitudinal reinforcement should be implemented in time according to design requirements and welded firmly.

(4) The length of single-cycle excavation should be controlled within 1 to 2 arches spacing according to the surrounding rock conditions. The steel frame spacing can be changed in time according to the surrounding rock conditions.

(5) During the supporting process, the plane warpage and verticality of the steel frame need to be strictly controlled. Attention should be paid to the construction angle and anchoring quality of the feet-lock bolts.

5 Technical Characteristics

Figures 8 and 9 respectively show the excavation situation of shanyang tunnel and the horizontal distance between the excavation of the inverted arch and the face of the upper bench. It can be found from

Fig. 8 Excavating by benching method in shanyang tunnel

Fig. 9 that the distance between the inverted arch and the tunnel face is within 16 m, with an average of 12.5 m, which meets the requirements of the traditional bench method within 40 m. In other words, the inverted arch construction in the proposed bench cut method can closely follow the excavation surface. In addition, the construction deformation curve of tunnel is displayed in Fig. 10. The subsidence displacement of the vault is smaller than the horizontal convergence deformation of the tunnel. The closure time from the excavation of the lower bench to the excavation of the invert is 5 days. After the excavation of the lower bench, the deformation of the vault and the horizontal convergence increases, and the deformation tends to be stable with the construction of the invert. Compared with the bench method, the micro bench cut method requires less time from excavation of the lower bench to the filling and closing of the invert. Therefore, the improved bench cut method can realize the initial support to be closed into a ring as soon as possible without increasing the corresponding equipment and personnel, increase the initial payment resistance, and achieve the purpose of safe and rapid construction.

(1) Micro bench cut method is a kind of construction method of fast excavation, fast support and fast looping. In soft rock sections, the method can well contain the deformation of initial support and achieve steady progress in tunnel construction.
(2) The construction process, the height and length of the benches is convenient to change during the transformation of surrounding rock. When the deformation of surrounding rock is large or sudden change, the method can be closed into a ring in time to effectively prevent the deformation and arch replacement accident.
(3) The impact of drilling blasting and blasting disturbance is avoided by combining the construction work with the twin header. In addition, the twin header can not only complete the deep milling operation, but also carry out the precise milling and trimming operation of the tunnel surface. The construction cost and maintenance cost of the equipment is low,

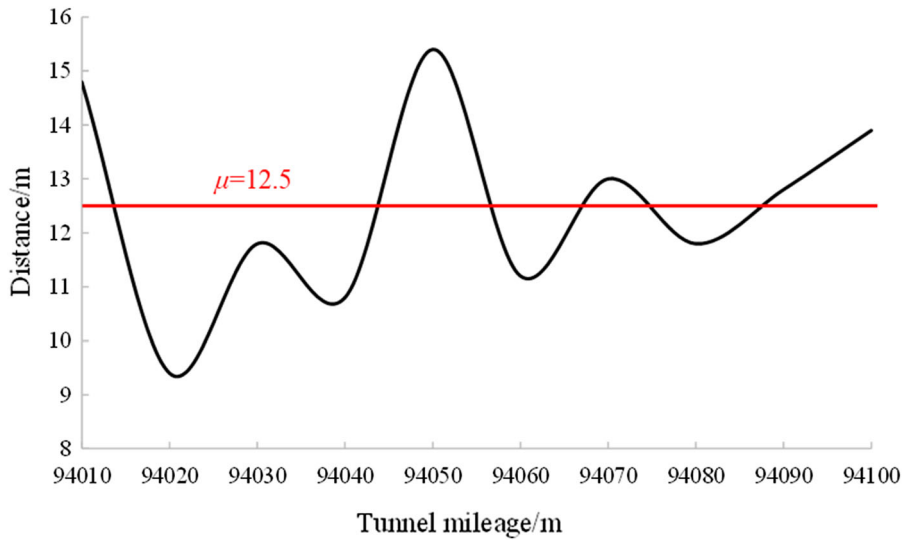


Fig. 9 The horizontal distance between the excavation of the inverted arch and the face of the upper bench

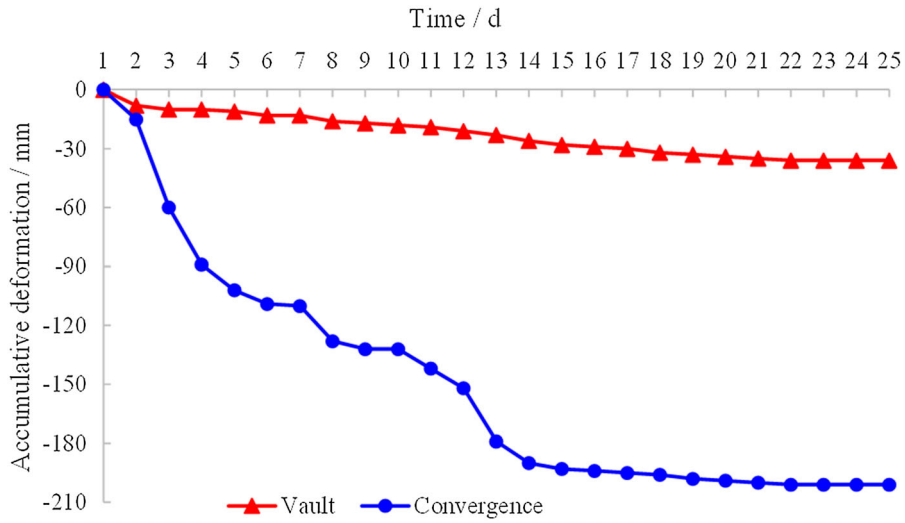


Fig. 10 The construction deformation curve of tunnel

and no other maintenance is required except for the replacement of milling cutter heads and bolts.

6 Conclusion and Discussion

(1) Construction technology of micro bench cut method can realize the rapid closure of the initial support into a ring in the weak rock tunnel with high in-situ stress. The use of twin header for the excavated surface can reduce the disturbance of drilling and blasting to surrounding rock, which realizes the "New Austrian Method" construction theory of less disturbance and effectively controls the convergence of the surrounding rock and the settlement of the vault.

(2) By using the construction technology of micro bench cut method, the narrow working surface of a single-line tunnel can be effectively utilized and the rapid construction of tunnel is also realized. Therefore, it can effectively avoid tunnel problems such as excessive tunnel safety distance and deformation intruded structure ambit.

(3) The horizontal convergence deformation of Shanyang tunnel is large and obviously larger than that of the subsidence displacement of the vault. Feet-lock bolt, reinforced grouting of arch foot surrounding rock, and expand support measures for arch foot are equipped to increase the stability and resistance of the supporting steel frame. The position of arch foot can be reinforced by concrete, which is used to prevent suspension on both sides of the arch foot.

(4) Auxiliary construction measures, such as advanced small pipe or grouting into the surrounding rock, are used for pre-reinforcement or pre-support of weak rock tunnel excavation.

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